Engineering Research Center for Reconfigurable Machining Systems

The University of Michigan, Ann Arbor

Creating the new manufacturing paradigm—Exactly the capacity and functionality needed, exactly when needed

A National Science Foundation Engineering Research Center since 1996

Consumer goods manufacturing is the foundation of the U.S. economy. But, to stay competitive, manufacturing companies must possess a new type of manufacturing system whose production capacity adjusts to respond to fluctuations in product demand and whose design can be upgraded with new processes capable of accommodating tighter product specifications. Current systems, even the so-called flexible manufacturing systems, do not have these characteristics. Cost-effective, reconfigurable manufacturing systems (RMSs), whose components are reconfigurable machines and reconfigurable controllers, as well as methodologies for their systematic design and diagnostics, are the cornerstones of this new manufacturing paradigm. The 30 industrial companies that joined the RMS Engineering Research Center are convinced that “reconfigurability” is as important a concept as mass production and lean manufacturing—maybe more important.

The following example illustrates the economic significance of reconfigurability. In the winter of 1996, the manufacturing lines producing a luxury car for a major automotive manufacturer were half-idle because of a low demand for these cars. At the same time, an unexpected demand for trucks made by this manufacturer exceeded supply by 20 percent. The manufacturer viewed building new manufacturing lines for trucks to supply the additional demand as a high-risk investment. The best solution would have been to reconfigure the manufacturing lines for the luxury car to produce trucks for a limited time. However, today’s technology does not allow such a change in manufacturing line functionality. The second-best solution would have been to rapidly increase the production capacity in the truck plant by 20 percent. But, again, today’s manufacturing systems are not designed for the addition of incremental capacity. The economic benefit of RMSs in such cases would be enormous.

Reconfigurability is defined as the ability to adjust the production capacity and functionality of a manufacturing system to new circumstances by a rearrangement or change of the system’s components. “Components” could be machines and conveyors in whole systems, mechanisms in individual machines, new sensors, or new controller algorithms. “New circumstances” may be changing product demand, producing a new product on an existing system, or integrating new process technology into existing manufacturing systems.

Why is ease of integration of new process technology so important? Let us elaborate through an example. Twenty-five years ago, drivers had to add engine oil every 1,000 miles. Today, such a need does not exist. This improvement is attributed to process technology—the ability to machine parts at higher precision—and to new engine technology, as well as new oils. Why did it take so long to implement this improvement? One of the major reasons is that the traditional machining lines for engines were not upgradable. They were closed systems with an estimated life expectancy of 15 to 20 years. Drivers had to wait for the construction of new machining systems that could utilize the new technology. By contrast, RMS technology would allow immediate implementation of such a product improvement by the integration of the needed process technology into existing reconfigurable systems. Delivering improved products in a shorter time frame is an important benefit to society.

Reconfigurable manufacturing systems will be open-ended so that they can be improved and upgraded rather than replaced. They will allow flexibility, not only in producing a variety of products, but also in changing the system itself. The key is that this type of system must be designed at the outset to be reconfigurable and must be created from basic hardware and software modules that can be arranged quickly and reliably.

Research

Using the narrow yet highly complex domain of machining systems, the Center will be able to contribute to a knowledge base for what could become known as “reconfiguration science.” This science will be generic and will be applicable to many production domains

Artist’s conception of the reconfigurable factory concept. (Credit: Rodney Hill)

(machining, assembly, semiconductor fabrication, and even the production of diapers). New configuration laws and principles are being developed, and available theories in fields related to reconfiguration science are being expanded and validated through experimental work in the Center's laboratory and in industrial plants.

Reconfiguration is being studied in the Center at two levels: (1) individual machines and their controls and (2) large systems consisting of many machines. At each level, we develop methodologies for rapid design and quick diagnostics and ramp-up. Accordingly, the research in the Center is organized into the four Clusters of Projects (COP) described below.

COP 1—Design of Reconfigurable Machine with Reconfigurable Controller
A design theory for reconfigurable machines (RM) and prototype machines is being developed simultaneously with that of process planners for RMs. The formulation of a modular control theory that enables quick integration of individual control algorithms to fit the RM configurations is underway. The principles of open-architecture control (OAC) that create the software framework for easy integration of controls from different vendors are being formulated. A combination of modular control and OAC will create the reconfigurable controller.

COP 2—Self-Diagnostics and Self-Calibrated Reconfigurable Machine
A new root-cause analysis methodology that uses in-process measurements of the produced part, process, and control errors for self-diagnostics of RMs is being developed. Geometric errors will be corrected automatically, and process parameters will be adjusted in real time.

COP 3—Design of Large Reconfigurable Machining Systems
A systematic design methodology (called "System Configurator") that links part-geometry and its annual volume to the selection of machines and their optimal configuration is being developed. This methodology includes a system-level process planner, analysis of the effect of the configuration on part quality, and life-cycle economic modeling.

COP 4—Ramp-Up for Large Reconfigurable Machining Systems
The University of Michigan (U-M) has experience in developing successful ramp-up methods for large assembly systems in automotive plants. This innovative methodology, which is based on real-time stochastic analysis, will be expanded to fit RMSs.

The Center also has five discipline based *research thrust areas*:

- System Design and Integration
- Software Architecture and Information
- Measurement and Controls
- Mechanical Design
- Processes and Tooling.

The five thrust areas and the four COPs create a matrix organization for a research program that contains some 15 projects. More than 30 faculty and approximately 40 graduate students participate in the research. In addition, the Center has developed activities that integrate the projects in each of the COPs, using case studies and testbed demonstrations.

Case Studies in Industrial Plants
Students are working in industrial plants to study reliability and diagnostics problems in machining systems. The data collected are being utilized by the COPs.

Testbed
An experimental testbed is being built at U-M to test the technology base of RMSs and demonstrate that they are upgradable, changeable, and quickly diagnosable. The RMS Center also encourages researchers from other universities to integrate their research results into the RMS testbed. The testbed contains several prototype machines designed to demonstrate concepts of RMs, open-architecture, and modular controls, as well as computer-aided process planning for RMS. All these machines and material handling systems are connected to a central system controller through communications software developed in the Center.

Education
The education goal of the RMS Center is to promote cross-disciplinary learning in a team environment and to provide students with a systems view of manufacturing. Training a new generation of engineers who possess knowledge of the design and maintenance of RMSs will be an important outcome of the Center. This program is built on three recent successes in innovative manufacturing education: the NSF Greenfield Coalition for Education in Manufacturing Engineering, the Program in Manufacturing (PIM), and the Tauber Manufacturing Institute (TMI).

PIM is a U-M cross-disciplinary program in engineering that requires industrial experience for admission. It offers the degrees of Master of Engineering and Doctor of Engineering in Manufacturing. Students take 20 to 30 percent of their courses in the Business School. The Center is a source of project and dissertation topics. TMI is a joint venture between the U-M College of Engineering and the Business School that primarily supports masters-level interdisciplinary engineering/business education through manufacturing enterprises, team project experience in industry, and the development of joint engineering/business curricula.

Both PIM and TMI are cornerstones of the Center/RMS education program. Other education programs at the Center include Research Experiences for Undergraduates for undergraduates from other U.S. universities; Minority Research Summer Fellowships, which offer research experience to selected students from groups under-represented in engineering; and summer workshops for communication skills and team- building.

Industrial Collaboration/Technology Transfer
More than 30 industrial companies are included among the founders of the RMS Center. Their interactions and contributions complete a three-way strategic partnership among technology suppliers (machine builders, control vendors, tooling and software companies), end users (aerospace, heavy equipment, and automotive), and university researchers.

Companies participating in the Center sustain a high level of interaction with the Center. A team effort involving both industry and academia is being carried out at all stages of the research and education programs. Half of the Center's Executive Committee is from industry. A Technical Advisory Committee consisting of all industrial members meets bi-annually to recommend priorities in the research program and to evaluate progress toward achieving the Center's goals. An industry-university Design and Integration Team defines the specifications for RMSs, benchmarks existing flexible machining systems, identifies new enabling technologies to be developed, and advises on the integration of the Center's projects. Finally, each project has several active industrial participants who meet bi-monthly with the project researchers to advise on research directions and to assess progress.

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